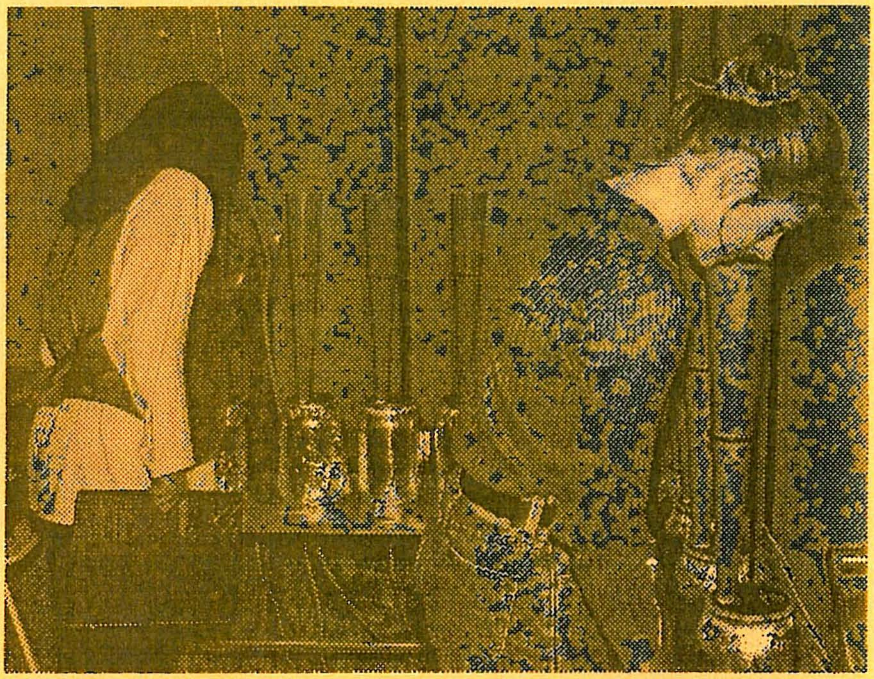
Perceived Air Quality in a Displacement Ventilated Room

Brohus, Henrik; Knudsen, Henrik Nellemose; Nielsen, Peter V.; Clausen, G.; Fanger, P. O.

Publication date:
1996

Document Version
Publisher's PDF, also known as Version of record

INSTITUTTET FOR BYGNINGSTEKNIK
DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITET • AAU • AALBORG • DANMARK



INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 61

Proceedings of Indoor Air '96, 7th International Conference on Air Quality and Climate, Nagoya, Japan, Vol. 1, pp. 811-816

H. Brohus , H. N. Knudsen, P. V. Nielsen, G. Clausen & P. O. Fanger

PERCEIVED AIR QUALITY IN A DISPLACEMENT VENTILATED ROOM

DECEMBER 1996 ISSN 1395-7953 R9653

Printed at Aalborg University

INSTITUTTET FOR BYGNINGSTEKNIK

DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITET • AAU • AALBORG • DANMARK

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 61

Proceedings of Indoor Air '96, 7th International Conference on Air Quality and Climate, Nagoya, Japan, Vol. 1, pp. 811-816

H. Brohus , H. N. Knudsen, P. V. Nielsen, G. Clausen & P. O. Fanger
PERCEIVED AIR QUALITY IN A DISPLACEMENT VENTILATED ROOM
DECEMBER 1996 ISSN 1395-7953 R9653

PERCEIVED AIR QUALITY IN A DISPLACEMENT VENTILATED ROOM

H. Brohus[1], H.N. Knudsen[2,3], P.V. Nielsen[1], G. Clausen[2] and P.O. Fanger[2]

[1] Department of Building Technology and Structural Engineering, Aalborg University, Denmark
[2] Laboratory of Heating and Air Conditioning, Technical University of Denmark, Denmark
[3] Present address: Danish Building Research Institute, Denmark

ABSTRACT

In a displacement ventilated room the non-uniform contaminant distribution causes an improved indoor air quality in the occupied zone compared with conventional mixing ventilation. This has been demonstrated in numerous studies by chemical measurements. In this study the air quality in a displacement ventilated room was determined directly by asking humans about how they perceived the air quality. A trained sensory panel comprising 12 subjects assessed the perceived air quality immediately after entering a climate chamber. The experiments showed that the perceived air quality in the displacement ventilated chamber was substantially better than in the case of mixing ventilation.

INTRODUCTION

In displacement ventilated rooms subcooled air is supplied in the lower part of the room with a low momentum. The cool air fills the room from below while "old" air is displaced upwards (1,2). Assisted by the convective currents from heat sources in the room, a stratified flow is created. A vertical temperature gradient will arise, which enables removal of exhaust air at ceiling level several degrees above the temperature in the occupied zone. If the pollution sources in the room are also heat sources the displacement ventilation system can have a high ventilation effectiveness. In this case the stratified flow implies that the room is separated in a lower, cleaner part and an upper, more contaminated part. The non-uniform contaminant distribution causes an improved indoor air quality in the occupied zone compared with conventional mixing ventilation. This has been demonstrated in numerous studies by chemical measurements (3,4,5,6). The chemical measurements are usually performed at steady-state conditions with stationary models of humans. Consequently, the results apply mainly for mid-term and long-term exposure assessments.

However, the perceived air quality is defined as the immediate impression of the indoor air quality experienced by the people entering a room (7). In that case it is crucial to consider the transient phenomena which occur when people are entering a room causing disturbances while they are inhaling room air and judging the air quality.

The objective of the study was to determine the indoor air quality in a displacement ventilated room directly by asking humans about how they perceived the air quality. The perceived air quality in the displacement ventilated room is then compared with conventional mixing ventilation to see if the indoor air quality is improved.

METHODS

Facilities

The study was performed in a climate chamber of stainless steel with a floor area of 9 m^2 and a height of 2.5 m (see Figure 1). Subcooled air was supplied through a perforated floor and exhausted through four openings in the ceiling. The supply air temperature was controlled to keep the air temperature in the breathing zone height close to 22°C during the experiments. Five light bulbs of 100 W located 0.1 m above the floor constituted heat sources.

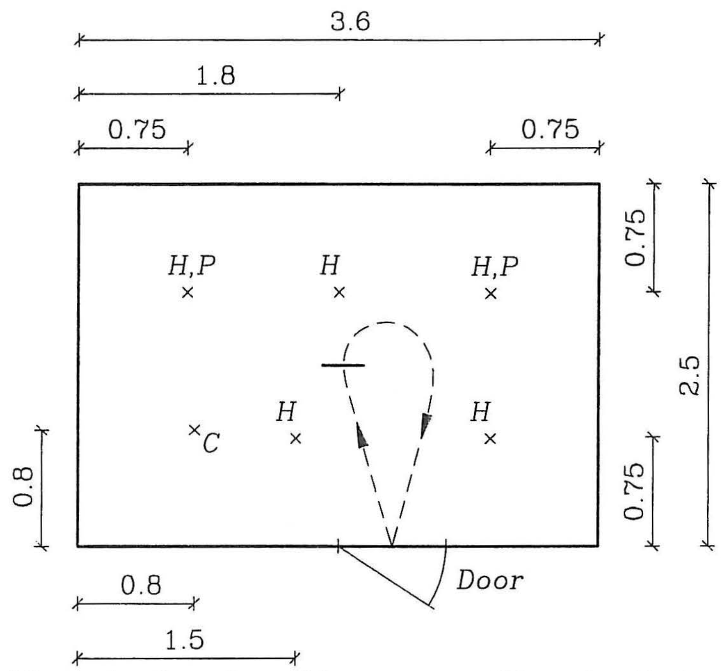


Figure 1. Location of heat sources (*H*) and pollution sources (*P*) in the climate chamber. Measurement location for the vertical concentration profile (*C*). The route of the subjects is shown by the dotted line. The bold line on the route shows where the subjects did the assessment. Measurements in m.

The contaminant distribution in the room was generated by two pollution sources. The pollution sources consisted of 2-propanone supplied via tubes just above the light bulbs 0.5 m above the floor (see Figure 2) . The 2-propanone was entrained and transported to the upper part of the room by the convective air current above the hot light bulbs. The vertical concentration profile of 2-propanone as well as the exhaust concentration was measured chemically by means of a gas analyser.

Sensory panel

A panel of 12 judges was trained to assess perceived air quality directly in the sensory unit, decipol (7). The panel was trained to assess the air quality in comparison with five known 2-propanone references ranging from 1 to 20 decipol. The contaminant concentration, c_{ppm}, was measured by means of a gas analyser in ppm 2-propanone and converted to perceived air quality, c_{dp}, in decipol by using the following formula (8)

$$c_{dp} = 0.84 + 0.22 \cdot c_{ppm}$$

The same formula is used for calibrating the references used by the sensory panel.

Test cases

Three test cases were examined in the study (see Table 1). The cases correspond to different concentration distributions generated by changing the air flow rate and the heat load, while the supply of pollution was kept approximately constant.

Table 1. Specification of the three test cases. In case C only the light bulbs below the two pollution sources were switched-on.

Case	No. of subjects	Heat load (W)	Air flow rate (m^3/h)
A	12	500	263
B	11	500	473
C	12	200	572

The heat load and the air flow rate were chosen to obtain different stratification heights, i.e. the height separating the room in the lower, cleaner zone and the upper, more contaminated zone. The aim was to obtain stratification heights below as well as above the breathing zone height. The average height of the panel was 1.79 m corresponding to a breathing zone height of 1.6 m.

Procedure

The experiment was performed over three days, one case a day, where the subjects of the panel assessed the perceived air quality one by one. There was an interval of approximately 15 minutes between each assessment to ensure that the flow field and the contaminant distribution were reestablished. The subjects were told to walk in a usual, calm speed and to follow a certain predetermined route in the chamber indicated on Figure 1. When they passed a certain location in the middle of the room they did the assessment and went out of the room again. The door to the climate chamber was operated by another person to ensure a minimum disturbance of the flow field before entering the room.

The vertical concentration profile of 2-propanone in the climate chamber was measured chemically both during the assessments as well as over a longer period with the same setup but without the panel (see Figures 3 - 5).

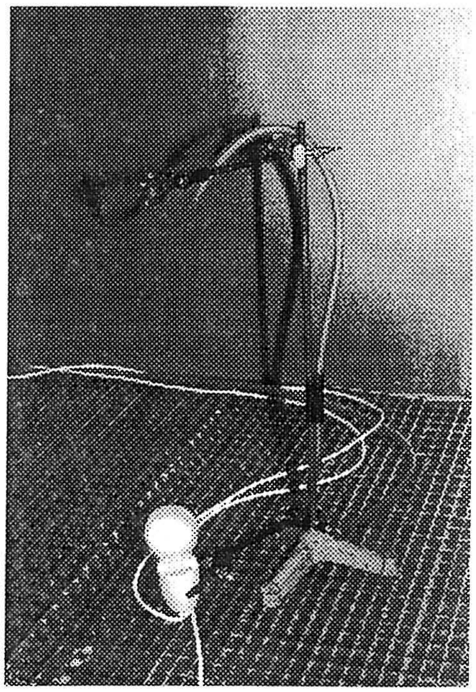


Figure 2. Photo of a heat source (100 W light bulb) and a tube delivering 2-propanone above the light bulb.

RESULTS

Figures 3 - 5 on the next page show the vertical contaminant concentration in the three test cases. The concentration profiles are expected to be representative for the whole room except in the close vicinity of the pollution sources and in the air current just above, i.e. no significant horizontal concentration gradient is expected to prevail in the displacement ventilated room (2). Table 2 shows the results of the assessments of the panel and the exhaust air quality.

Table 2. Perceived air quality assessed by the sensory panel and concentration in the exhaust air measured by means of a gas analyser and converted to decipol using the above formula.

Case	Exhaust air quality (decipol)	Perceived air quality (decipol)
A	47	18
B	23	8
C	29	6

DISCUSSION

The concentration measurements show a highly stratified flow with a very low concentration at the floor level increasing strongly with the height. A significant separation of the cleaner, lower part of the room and the upper, more contaminated part is found. The stratification height is seen to range from a level below the breathing zone height (case A, Figure 3) to a level above the breathing zone height (case C, Figure 5).

If the measurements without the panel in the room are compared with the measurements where the subjects visited the room one by one, a good correspondence is seen. This indicates that the flow field has been stable during the experiments and that the subjects have been exposed to almost the same indoor environment in the climate chamber.

This is a typical example of concentration distributions in a displacement ventilated room. If the chamber had been ventilated after the mixing principle, the concentrations would be uniform and equal to the exhaust concentrations mentioned in Table 2 in the ideal case. This reveals a high ventilation effectiveness in the occupied zone with a local concentration significantly below the exhaust concentration.

The objective of the study was to see if the high ventilation effectiveness measured chemically also applied when humans were asked directly about how they perceived the air quality. The experiments showed that the perceived air quality in the displacement ventilated room was substantially better than in the case of mixing ventilation. The concentration measured in decipol was assessed to be 3 - 5 times lower than the case of mixing ventilation, for instance in case C the panel assessed the air quality to be 6 decipol when the concentration in the exhaust air was 29 decipol. This difference exceeds the usual ventilation effectiveness found in displacement ventilated rooms (9).

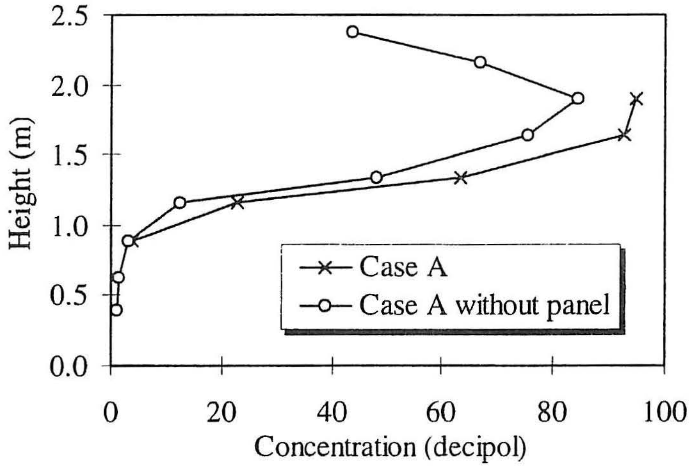


Figure 3. Concentrations measured chemically for case A.

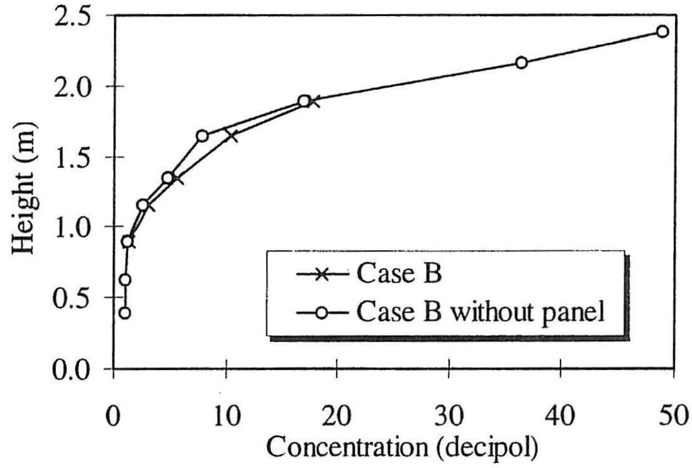


Figure 4. Concentrations measured chemically for case B.

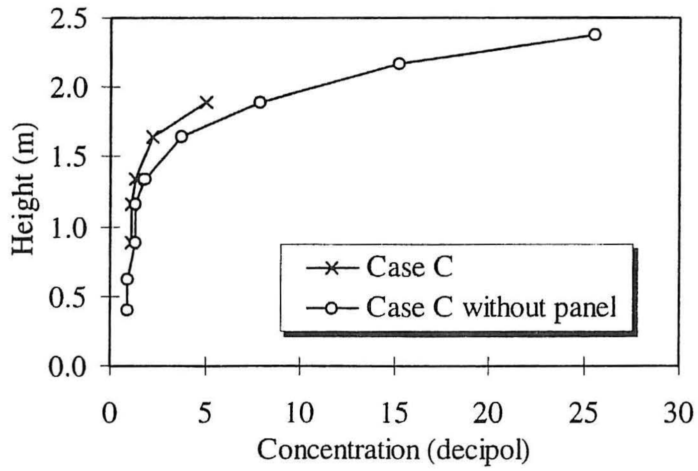


Figure 5. Concentrations measured chemically for case C.

In this study the disturbances of the flow field in the chamber was minimized. Apart from the subjects of the panel and the door operation no disturbances took place. In a real room there will be frequent disturbances from occupants, opening of doors, cold down draught from windows etc. At the same time the efficiency of the ventilation system will presumably be lower than in this case where the clean air was supplied through the entire perforated floor. The combined effect of these parameters will be a lower ventilation effectiveness and thereby a worse perceived air quality. More research on this topic is obviously needed

Despite the inevitable differences between climate chamber measurements and the conditions in a real ventilated room the results are promising, indicating that the improved indoor air quality found in displacement ventilated rooms using chemical measurements may be confirmed by asking humans directly.

ACKNOWLEDGEMENTS

This research was supported financially by the Danish Technical Research Council (STVF) as part of the research programme "Healthy Buildings", 1993- 1997.

REFERENCES

1. Breum, N.O. 1992. "Flow Fields of Simulated Body Odor in an Office Ventilated from the Displacement Design Principle", *Proceedings of Roomvent '92, Air Distribution in Rooms, Third International Conference*, Vol. 3, pp.181-194, Aalborg, Denmark.
2. Nielsen, P.V. 1993. *Displacement Ventilation - theory and design.* ISSN 0902-8002 U9306, Department of Building Technology and Structural Engineering, Aalborg University, Denmark.
3. Holmberg, R.B.; Eliasson, L.; Folkesson, K.; and Strindehag, O. 1990. "Inhalation-Zone Air Quality Provided by Displacement Ventilation". *Proceedings of Roomvent '90, International Conference on Air Distribution in Ventilated Spaces*, Oslo, Norway.
4. Brohus, H. and Nielsen, P.V. 1994. "Personal Exposure in a Ventilated Room with Concentration Gradients", *Proceedings of Healthy Buildings '94, 3rd International Conference on Healthy Buildings*, Vol.2, pp.559 - 564, Budapest, Hungary.
5. Krühne, H. and Fitzner, K. 1994. "Air Quality in the Breathing Zone in Rooms with Displacement Flow" , *Proceedings of Roomvent '94, Air Distribution in Rooms, Fourth International Conference*, Vol.2, pp.93-101, Cracow, Poland.
6. Mundt, E. 1994. "Inhaled Air in Displacement Ventilation", *Proceedings of Healthy Buildings '94, 3rd International Conference on Healthy Buildings*, Vol.2, pp.355-360, Budapest, Hungary.
7. Fanger, P.O. 1988. Introduction of the Olf and Decipol Units to Quantify Air Pollution Perceived by Humans Indoors and Outdoors. *Energy and Buildings*, 12:1-6.
8. Bluyssen, P. and Fanger, P.O. 1991. "Addition of Olfs from Different Pollution Sources, Determined by a Trained Panel". *International Journal of Indoor Air Quality and Climate*, Vol.1, 4, pp. 414-421.
9. European Concerted Action. Indoor air Quality and its Impact on Man. Report No. 11: Guidelines for ventilation requirements in buildings. Commision of the European Communities, Luxemburg, 1992.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 34: T. V. Jacobsen, P. V. Nielsen: *Numerical Modelling of Thermal Environment in a Displacement-Ventilated Room.* ISSN 0902-7513 R9337.

PAPER NO. 35: P. Heiselberg: *Draught Risk from Cold Vertical Surfaces.* ISSN 0902-7513 R9338.

PAPER NO. 36: P. V. Nielsen: *Model Experiments for the Determination of Airflow in Large Spaces.* ISSN 0902-7513 R9339.

PAPER NO. 37: K. Svidt: *Numerical Prediction of Buoyant Air Flow in Livestock Buildings.* ISSN 0902-7513 R9351.

PAPER NO. 38: K. Svidt: *Investigation of Inlet Boundary Conditions Numerical Prediction of Air Flow in Livestock Buildings.* ISSN 0902-7513 R9407.

PAPER NO. 39: C. E. Hyldgaard: *Humans as a Source of Heat and Air Pollution.* ISSN 0902-7513 R9414.

PAPER NO. 40: H. Brohus, P. V. Nielsen: *Contaminant Distribution around Persons in Rooms Ventilated by Displacement Ventilation.* ISSN 0902-7513 R9415.

PAPER NO. 41: P. V. Nielsen: *Air Distribution in Rooms - Research and Design Methods.* ISSN 0902-7513 R9416.

PAPER NO. 42: H. Overby: *Measurement and Calculation of Vertical Temperature Gradients in Rooms with Convective Flows.* ISSN 0902-7513 R9417.

PAPER NO. 43: H. Brohus, P. V. Nielsen: *Personal Exposure in a Ventilated Room with Concentration Gradients.* ISSN 0902-7513 R9424.

PAPER NO. 44: P. Heiselberg: *Interaction between Flow Elements in Large Enclosures.* ISSN 0902-7513 R9427.

PAPER NO. 45: P. V. Nielsen: *Prospects for Computational Fluid Dynamics in Room Air Contaminant Control.* ISSN 0902-7513 R9446.

PAPER NO. 46: P. Heiselberg, H. Overby, & E. Bjørn: *The Effect of Obstacles on the Boundary Layer Flow at a Vertical Surface.* ISSN 0902-7513 R9454.

PAPER NO. 47: U. Madsen, G. Aubertin, N. O. Breum, J. R. Fontaine & P. V. Nielsen: *Tracer Gas Technique versus a Control Box Method for Estimating Direct Capture Efficiency of Exhaust Systems.* ISSN 0902-7513 R9457.

PAPER NO. 48: Peter V. Nielsen: *Vertical Temperature Distribution in a Room with Displacement Ventilation.* ISSN 0902-7513 R9509.

PAPER NO. 49: Kjeld Svidt & Per Heiselberg: *CFD Calculations of the Air Flow along a Cold Vertical Wall with an Obstacle.* ISSN 0902-7513 R9510.

PAPER NO. 50: Gunnar P. Jensen & Peter V. Nielsen: *Transfer of Emission Test Data from Small Scale to Full Scale.* ISSN 1395-7953 R9537.

PAPER NO. 51: Peter V. Nielsen: *Healthy Buildings and Air Distribution in Rooms.* ISSN 1395-7953 R9538.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 52: Lars Davidson & Peter V. Nielsen: *Calculation of the Two-Dimensional Airflow in Facial Regions and Nasal Cavity using an Unstructured Finite Volume Solver.* ISSN 1395-7953 R9539.

PAPER NO. 53: Henrik Brohus & Peter V. Nielsen: *Personal Exposure to Contaminant Sources in a Uniform Velocity Field.* ISSN 1395-7953 R9540.

PAPER NO. 54: Erik Bjørn & Peter V. Nielsen: *Merging Thermal Plumes in the Indoor Environment.* ISSN 1395-7953 R9541.

PAPER NO. 55: K. Svidt, P. Heiselberg & O. J. Hendriksen: *Natural Ventilation in Atria - A Case Study.* ISSN 1395-7953 R9647.

PAPER NO. 56: K. Svidt & B. Bjerg: *Computer Prediction of Air Quality in Livestock Buildings.* ISSN 1395-7953 R9648.

PAPER NO. 57: J. R. Nielsen, P. V. Nielsen & K. Svidt: *Obstacles in the Occupied Zone of a Room with Mixing Ventilation.* ISSN 1395-7953 R9649.

PAPER NO. 58: C. Topp & P. Heiselberg: *Obstacles, an Energy-Efficient Method to Reduce Downdraught from Large Glazed Surfaces.* ISSN 1395-7953 R9650.

PAPER NO. 59: L. Davidson & P. V. Nielsen: *Large Eddy Simulations of the Flow in a Three-Dimensional Ventilated Room.* ISSN 1395-7953 R9651.

PAPER NO. 60: H. Brohus & P. V. Nielsen: *CFD Models of Persons Evaluated by Full-Scale Wind Channel Experiments.* ISSN 1395-7953 R9652.

PAPER NO. 61: H. Brohus, H. N. Knudsen, P. V. Nielsen, G. Clausen & P. O. Fanger: *Perceived Air Quality in a Displacement Ventilated Room.* ISSN 1395-7953 R9653.

PAPER NO. 62: P. Heiselberg, H. Overby & E. Bjørn: *Energy-Efficient Measures to Avoid Downdraft from Large Glazed Facades.* ISSN 1395-7953 R9654.

PAPER NO. 63: O. J. Hendriksen, C. E. Madsen, P. Heiselberg & K. Svidt: *Indoor Climate of Large Glazed Spaces.* ISSN 1395-7953 R9655.

PAPER NO. 64: P. Heiselberg: *Analysis and Prediction Techniques.* ISSN 1395-7953 R9656.

PAPER NO. 65: P. Heiselberg & P. V. Nielsen: *Flow Element Models.* ISSN 1395-7953 R9657.

PAPER NO. 66: Erik Bjørn & P. V. Nielsen: *Exposure due to Interacting Air Flows between Two Persons.* ISSN 1395-7953 R9658.

PAPER NO. 67: P. V. Nielsen: *Temperature Distribution in a Displacement Ventilated Room.* ISSN 1395-7953 R9659.

PAPER NO. 68: G. Zhang, J. C. Bennetsen, B. Bjerg & K. Svidt: *Analysis of Air Movement Measured in a Ventilated Enclosure.* ISSN 139995-7953 R9660.

Department of Building Technology and Structural Engineering
Aalborg University, Sohngaardsholmsvej 57. DK 9000 Aalborg
Telephone: +45 9635 8080 Telefax: +45 9814 8243